SIMULATIONS OF ATMOSPHERIC FLOWS IN THE BOUNDARY LAYER OVER INHOMOGENEOUS SURFACE CONDITIONS

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LONG TERM GOALS

The goal of this project is to improve the description and prediction of resolvable and subgrid-scale atmospheric fields over inhomogeneous surfaces and to develop an integrated modeling system for weather phenomena and dispersion effects on a spectrum of spatial and temporal scales.

OBJECTIVES

Specific objectives include: 1) developing a fully-compressible and computationally efficient model that can be applied to atmospheric and dispersion fields on microscale to mesoscale domains, 2) investigating turbulence transfer within the atmospheric boundary layer, and 3) formulating a concept of nonlocal turbulent mixing. This work is supported by the Office of Naval Research, Marine Meteorology and Atmospheric Effects.

APPROACH

We have developed a fully-compressible, 2D atmospheric model based on the MacCormack numerical scheme, a subgrid-scale turbulence transfer algorithm, and an interactive shortwave radiation scheme based on the Monte Carlo method (Koračin et al. 1997a, website 1). To simulate atmospheric transport and dispersion, we developed a Lagrangian particle model (LAP, Koračin et al. 1997d, websites 3-5) which uses data from measurements or atmospheric model results as input. Our approach to the LAP model involved a new treatment of the range of randomness derived from the turbulence kinetic energy. In order to gain confidence in dispersion estimates, we also developed a novel approach to evaluating predicted atmospheric fields in complex terrain by using tracer measurements (Koračin et al. 1997c).

We have also developed a new approach to nonlocal mixing applicable to different models. Our method uses Donaldson's set of so called "super-equilibrium equations" for initial fields and then determines nonlocal mixing potential from an integrated value of the turbulence kinetic energy and momentum fluxes (Koračin and Isakov 1997; Koračin et al. 1997b, website 2).

WORK COMPLETED

Work involved the reproduction of several published numerical experiments appropriate to fully-

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compressible models. A simulation of a buoyant bubble in a neutral environment closely correlated with results from Droegemeier's fully compressible model. The same experiment using a compressible Advanced Regional Prediction System (ARPS) led to similar results. Our model, including the Monte Carlo radiation scheme, was also evaluated using Nicholls' (1984) measurements over the North Sea. The model evaluation and analysis of simulation results were presented by Koračin et al. (1997a).

The LAP model was applied to data from a tracer experiment conducted in complex terrain (Koračin et al. 1997d, website 4). Atmospheric fields of various complexities were evaluated by using the Tracer Potential method (Koračin et al. 1997c) prior to being used as input to the dispersion model. This method for determining nonlocal mixing was applied to an idealized convective experiment as well as to data from the first Lagrangian period of the Atlantic Stratocumulus Transition Experiment (ASTEX) (Koračin and Isakov 1997; Koračin et al. 1997b, website 2; Tjernström et al. 1997).

RESULTS

The destruction of a "hot" buoyant bubble was simulated by the recently developed fully-compressible atmospheric model (Fig. 1) (Koračin et al. 1997a, website 1). The model retained computational stability while simulating vertical motions ranging between -11 ms^{-1} and 22 ms^{-1}. A numerical experiment with a broken-cloud field indicated several important issues in using the Monte Carlo scheme in mesoscale and cloud-resolving models: accuracy was determined by the number of photons used in the experiment (at least 10,000 photons were found to be necessary to provide 2% accuracy in flux calculations); the most critical parameter in shortwave flux calculations was found to be cloud optical thickness; and geometry of cloud elements was also important.

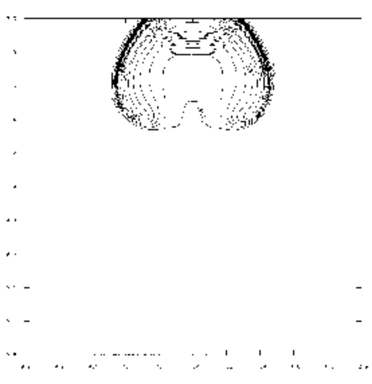

Figure 1 Contour plot of potential temperature (K) representing positively buoyant bubble in neutral environment.

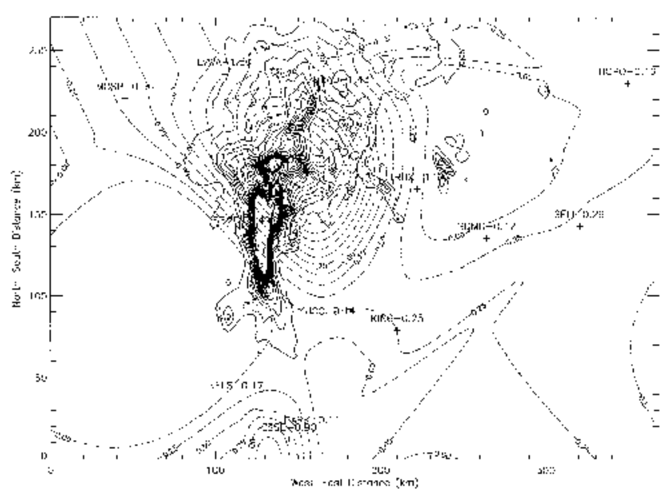

Figure 2 Measured (dashed) and simulated by LAP (solid line) contours of SF_6 surface tracer concentrations in the southwest U.S. averaged from 6-14 August 1992.

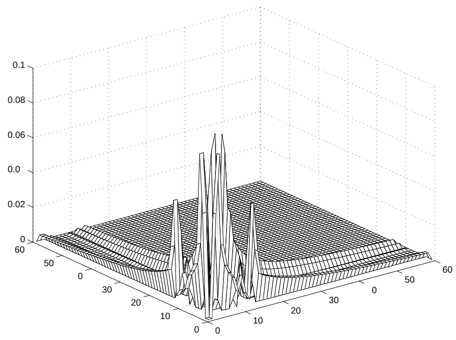

Figure 3 Non-diagonal coefficients of the transilient matrix describing turbulent transfer.

The LAP model reproduced the main features of measured tracer concentrations in complex terrain at distances from the source ranging from 20 to 300 km, including channeling of the transported tracers (Fig. 2). The LAP model simulated the correct order of magnitude of tracer concentration and reproduced similar temporal patterns as measurements.

According to preliminary results of the method for determining nonlocal turbulent transfer, nonlocal mixing contributed to evolution of the boundary layer by approximately 10% as compared to local mixing in the stratocumulus case (Fig. 3). The contribution increased to approximately 30-40% in the convective test case (Koračin and Isakov 1997; Koračin et al. 1997b, website 2).

IMPACT

The models and methods we have developed will increase understanding and lead to improved prediction of the atmospheric boundary layer, particularly in the areas of turbulence transfer and atmospheric transport and dispersion. This has obvious application to naval and aircraft operations as well as to defense against chemical or biological weapons. Most of the models can be operated on a PC platform, permiting use by tactical military units.

TRANSITIONS

The cloud-resolving numerical model will be adapted and available for operational applications. A research team from Flinders University in Australia would like to obtain the code and use it for studies of broken clouds off the Australian coast. Faculty at the University of Zagreb in Croatia would like to use the model for air quality studies in complex terrain and along the Adriatic coast. A team from the University of Uppsala in Sweden plans to use our method of nonlocal mixing in a collaborative study of the ASTEX data. The Naval Postgraduate School in Monterey is interested in obtaining high resolution atmospheric data as input for ocean models.

RELATED PROJECTS

Work on this project benefitted from experience and results from another ONR-funded project (N00014-96-1-0980) focused on simulations of coastal dynamics. Darko Koračin is also a P.I. on this project. Performance has been enhanced by collaboration with Dr. Luis Mendez of the University of California, Davis, and Dr. Michael Tjernström of the University of Uppsala, Sweden. Research conducted in this project has led to submission of a proposal to DOD-ONR focused on modeling the dispersion of vapor and aerosol particulates in complex terrain as well as a proposal (with NCEP) to NOAA to develop a high resolution, compressible ETA model. The Tracer Potential method and Lagrangian model were also used in several EPA-related projects (website 4) as well as in planning a modeling study for a future airport near Las Vegas (website 3) and the NOAA-funded weather modification program (website 5).

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Website 5: http://www.dri.edu/ResearchAreas/Modeling/wmod.html